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The extent of knowledge of Quick Response Manufacturing principles: an exploratory transnational study

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Abstract: The main goal of this research is to identify whether companies that have implemented the Quick Response Manufacturing (QRM) approach have full knowledge of the QRM principles or have merely applied the elements (principles and tools) that have a close relationship with Lean Manufacturing. Based on a review of the literature regarding the QRM principles, an exploratory survey was conducted for over 20 manufacturing companies from Brazil, Europe and the USA that operate in an Engineer or Make to Order environment system and explicitly have conducted QRM journeys. The results of the present study show that (i) the surveyed companies have difficulty knowing and applying some of the exclusive elements of this approach, even if they started implementing QRM several years ago; (ii) the surveyed companies' knowledge degree over QRM exclusive elements is apparently higher among US-based companies due to better trained employees and better dissemination and awareness of the QRM exclusive elements; and (iii) a mentality based on productivity, low costs and due date delivery was identified as the main barrier for companies to achieve a higher knowledge degree regarding QRM.

Keywords: Quick Response Manufacturing, Lean Manufacturing, Lead Time, exploratory survey, QRM principles knowledge

1. Introduction

Over the past few decades, time has become a strategic factor for business competitiveness (Stalk Jr. 1989; Demeter, 2013) due to customers' increasing reluctance to accept long delivery timeframes (Bower and Hout 1988). At the same time, companies' flexibility and adaptability have become vital factors regarding an organization's ability to respond quickly enough to customer demands for product variety, high quality, low price and short lead times (Suri 1998, 2010a). Although some goods produced by factories have increased in aspects of sophistication, the time spent for its entire production still represents a small fraction of time compared to the total period they remain in the factory. The current cycle times are the same or marginally better than those half a century ago (Ignizio 2009).

The importance of reducing lead time was first shown in the Toyota Production System concepts, through their focus on flow and just in time. The Toyota way have been popularized in the West as Lean Manufacturing (Womack, Jones, and Roos 1990; Womack and Jones 1996). In 1998, Rajan Suri proposed a new alternative and complementary approach to Lean Manufacturing called Quick Response Manufacturing (QRM). Such approach focuses its efforts on reducing the lead time in environments characterized by a high variety of products and customization.

Despite the fact that Lean Manufacturing and QRM are similar in many ways (principles and tools), QRM has emerged to complement Lean Manufacturing in environments with high levels of product variety and to include some new and exclusive elements that distinguish it from Lean Manufacturing (Suri 2010b), for example, the use of certain specific tools, such as the POLCA system (Vandaele et al, 2008; Krishnamurthy and Suri 2009; Riezebos, 2010; Chinet and Godinho Filho 2014) and the use of the Manufacturing Critical-Path Time (MCT) metric (Suri, 2014).

In addition, another two core concepts stated by Suri (2010a) differentiate QRM from Lean Manufacturing: (i) the power of time (concerns the replacement of traditional productivity, cost and on-time delivery metrics using reduction of the lead time as the unique comprehensive performance measurement); and (ii) understanding and exploiting system dynamics (understanding the relationship between the variables that have an effect on the lead time and, therefore, giving better guidance to the improvement efforts for these variables to maximize their effects on the reduction of lead time). Suri (1998, 1998 2010a, 2010b) and much of the literature on QRM (Godinho Filho and Veloso Saes, 2013) states that both aspects are essential within QRM. Although essential, the deep knowledge of such concepts involves a complete redesign in the way the company is managed (Doll and Vonderembse 1991; Ericksen et al. 2005) and is, in theory, one of the main obstacles to QRM implementation (Suri 1998, 2010a). Thus, companies in the process of QRM implementation may find it difficult to inject such QRM exclusive concepts into their culture and thus limit themselves solely to applying the simpler and more widespread elements (principles and tools) that are common to both paradigms. Within this context, the present paper aims to assess whether companies worldwide who have been implementing QRM have correct knowledge of all elements of Quick Response Manufacturing. This assessment is performed by means of an exploratory study of companies from Brazil, USA and Europe that have been on the QRM track.

To fulfil its objectives, this study, through a literature review, first divides the QRM elements into two groups: (i) exclusive elements of QRM ("exclusive"); and (ii) elements common to the Lean Manufacturing and QRM approaches ("common"). Next, the study tests the hypothesis of no differences in companies' knowledge with respect to both groups of QRM elements. The study aims to contribute to more extensive knowledge and implementation of QRM principles within companies.

Currently available QRM literature mostly covers the description and development of QRM's principles, e.g., Suri (2014) and Suri (1998, 2010a), and case studies on its implementation, e.g., Fernandes et al. (2012), Veloso Saes and Godinho Filho (2011), and the POLCA (Paired-cell Overlapping Loops of Cards with Authorization) system implementation, e.g., Chinet and Godinho Filho (2014), Fernandes and do Carmo-Silva (2006), Germs and Riezebos (2010), Krishnamurthy and Suri (2009), Suri (1998), and Vandaele et al. (2008). Godinho Filho and Veloso Saes (2013), through a review of literature on reducing lead time within the context of Time-Based Competition and QRM, concluded that much of the literature on the subject is quite limited with regard to practical studies, with some little exception (for example Vandaele et al, 2008). There are not, for example, studies in the literature that assess to what extent the principles and tools of the QRM approach are known by the companies that have the lead time as their main competitive criterion. This study aims to contribute to filling this gap. The study that comes closest to the purpose of this work is the master thesis of Hoonte (Hoonte, 2012), in which was performed a multiple case study in companies in the Netherlands, Norway, and Austria, aiming to develop a model of QRM maturity to be used by companies as a self-assessment tool to identify opportunities for improvement.

The remainder of this paper is organized as follows: section 2 presents the basic concepts of Lean Manufacturing and QRM, as well as the theoretical framework necessary to the present research; section 3 describes the research method used and the hypotheses formulated for this study; section 4 presents and discusses the results; and section 5 draws the conclusions.

2 Theoretical Framework

2.1 Lean Manufacturing and Quick Response Manufacturing: basic concepts

Toyota Production System (TPS) emerged in Japan in the mid-1950s and has developed gradually over many years as a result of the accumulation of a series of small innovations (Fujimoto 1999). At the time, the country, had been defeated in World War II, was facing a severe shortage of resources and very low productivity (Shingo 1981). Toyota did not have the production scale and neither the same amount of resources that Ford and GM had, which made it impossible to compete based on productivity (Ohno 1988), as was done by the American automobile companies. As a consequence, it has begun the development of a series of tools focusing on the elimination of waste, which became known as Lean Manufacturing at the end of the 1980s. Lean Manufacturing places two management goals above any other: continuous improvement and the constant combat of waste reduction (Lander and Liker 2007; Liker and Meier 2005). According to Ohno (1988), the main creator of TPS, it is possible to identify seven types of MUDA (Japanese word for waste), which include all activities in production processes that do not add value for the customer and therefore should be eliminated.

The literature contains a large number of elements associated with Lean Manufacturing. Table 1 shows these elements based on recent reviews of the literature and questionnaires on the subject (Godinho Filho et al, 2016; Jasti and Kodali, 2015; Marodin and Saurin, 2013; Shah and Ward, 2007; Li et al., 2005; Ketoviki and Schroeder, 2004; Nahm, et al., 2004; Cua, et al., 2001; Tu, et al., 2001; Ward, et al., 1998; Koufteros, et al., 1998, 2005).

<Insert Table 1>

Lean Manufacturing has been very popular for repetitive processes with many variants, but low or any customization. In 1998, Rajan Suri (Suri, 1998) proposed a new approach for low volume, high variety production systems, which required a different focus on process improvement and performance: the Quick Response Manufacturing approach. This approach uses a mathematical foundation that explores the concepts of Queuing Theory and Systems Dynamics (Sterman, 2000) to formulate a set of principles for restructuring the shop floor and management practices. Furthermore, QRM presents a new approach to planning and controlling materials in manufacturing environments to work with a high product mix and proposes new performance indicators. The QRM approach is built on ten key principles proposed by Suri (1998), shown in Table 2.

<Insert Table 2>

To better distilling the ten key principles presented above, Suri (2010a) established four core concepts of the QRM strategy:

(1) The power of time: complete replacement of traditional cost-based goals on efficiency and utilization with QRM’s time-based goals, which is a relentless focus on lead time reduction;

(2) Organizational structure: the organizational structure of the company should be reviewed, focusing on the reduction of lead time; the main point of this change is the shift of the shop floor layout from process layout to a QRM cell;

(3) Understanding and Exploiting System Dynamics: understand the relationship between the variables that have an effect on the lead time and therefore give better guidance to the improvement efforts for these variables to maximize their effects on the reduction of lead time;

(4) Reduction of lead time globally at the company: QRM must be applied to the entire company, including for example, the supply chain, office and sales operations, engineering and product development.

2.2 Similarities and differences between Lean Manufacturing and QRM: QRM's exclusive elements

The purpose of this section is to highlight the elements that specifically characterize QRM and those that are common to the QRM and Lean Manufacturing approaches. In order to accomplish this goal, the literature on both approaches was reviewed. Because they are extensively studied subjects (mainly Lean Manufacturing), performing a full review of the literature on both subjects would be impractical; in addition, there are current literature reviews on both subjects that could be used for the identification of such elements.

Concerning Lean Manufacturing, two recent literature reviews have been used: Jasti and Kodali (2015) and Marodin and Saurin (2013). In addition, several questionnaires on the topic were also used (Shah and Ward, 2007; Li et al., 2005; Ketoviki and Schroeder, 2004; Nahm, et al., 2004; Cua, et al., 2001; Tu, et al., 2001; Ward, et al., 1998; Koufteros, et al., 1998, 2005). Concerning QRM, we refer to the work of Godinho Filho and Veloso Saes (2013) and Riezebos (2010). Furthermore, the elements of each approach were also searched for in classical references of both approaches (Lander and Liker, 2007; Liker and Meier, 2005; Ohno, 1988; Shingo, 1981; Suri, 1998, 2010a; Womack and Jones, 1996; Womack, Jones, and Roos, 1990). From this analysis, there was an initial list of elements common to both approaches. This list was submitted to three experts in each approach that have ratified the elements, which are in Table 3.

<Insert Table 3>

The elements identified as being part of QRM and not included in the list of elements common to both approaches are the exclusive elements of QRM. These elements were also passed to three specialists in the QRM theme, who, after detailed analysis, ratified such elements. Basically, these elements are a constituent part of the core concepts # 1 (The power of time), # 3 (System Dynamics) and # 4 (Enterprise-wide application) of the QRM approach and are shown below.

2.2.1 The QRM approach's exclusive elements regarding core concept #1: The Power of Time

In the context of this core concept, which advocates that an entirely new way based on time must be found to manage the company, (Suri 2010a) identifies two exclusive elements to this approach. Unlike Lean Manufacturing, which seeks to reduce costs and inventories through the elimination of all waste throughout the production process of the enterprise (Ohno, 1988; Shingo, 1981; Womack and Jones, 1996), the central goal of QRM is lead time reduction in all operational aspects of the organization (Godinho Filho and Veloso Saes 2013; Suri 1998, 2010a). QRM focuses its attention on reducing the total time required to deliver a product, represented by the time of the manufacturing critical-path (Suri, 2014).

As a second exclusive element of the QRM approach we have identified its focus on lead time performance as the main performance measure. Improvement of the traditional performance indicators, such as the reduction of inventory and production costs, productivity and quality gains, etc., takes place as a result of the strategy focused on reducing lead time (Suri, 1998, 2010a). The opposite occurs with other approaches, in which the reduction of lead time is a consequence of prioritizing other performance measures. Still, in this context, as stated above, punctuality of deliveries should not be measured and rewarded because it causes a plethora of dysfunctional effects that end up lengthening the lead time (Suri, 2010a).

2.2.2 QRM's exclusive elements' approach relative to core concept #3: Understanding and Exploiting Systems Dynamics

Lean Manufacturing typically treats variability as cause for waste. In addition to this type of variability, Suri (1998, 2010a) introduces the so-called good variability that may be exploited as a business strategy. Therefore, within QRM, it is vital to know the difference between both types of variability.

Additionally, Hopp and Spearman (2007) describe three possibilities for mitigating the effects of variability: retain idle capacity (free time), hold inventory or work with longer lead times. For a better description of these three fundamental types of buffer, see Vandaele and De Boeck (2003). Suri (1998, 2010a) states that although many manufacturing managers currently believe that it is necessary to keep machines and people busy constantly to conduct the work as rapidly as possible and to reduce the lead times, this policy of keeping 100% capacity utilization causes high levels of Work In Process (WIP) and long lead times. In addition, the use of productivity as a performance evaluation criterion works counter-productive to the lead time reduction. Thus, QRM recommends seeking gains in flexibility and agility rather than maximizing the use of equipment and personnel, i.e., with respect to critical resources, usage of only 70% to 80% of the installed capacity should be planned. This, coupled with the practice of working with a short and precise planning horizon, avoids long lead times, growth of queues and idle jobs waiting for resources (Suri, 1998, 2010a).

Regarding the planning and production control system in QRM cells, the use of POLCA (*Paired-cell Overlapping Loops of Cards with Authorization*), a hybrid system that pulls and pushes the production, combining the best features of MRP systems (Pushed) and card based systems (Pulled) (Vandaele et al, 2008; Fernandes and Carmo-Silva, 2006; Riezebos, 2010; Krishnamurthy and Suri, 2009; Suri 1998) is recommended.

2.2.3 QRM's exclusive elements regarding core concept #4: Enterprise-wide application

The management of most manufacturing organizations is still based on economies of scale and a cost reduction mentality and thereby incurs a series of dysfunctional effects that is denominated in QRM as a Response Time Spiral (Suri, 2010a).

With respect to suppliers, there is a standard practice in purchasing: because items with long lead times are often ordered in large batches, one should negotiate quantity discounts with suppliers due to the amounts being acquired. The problem with such belief is that it results in a Response Time Spiral for purchasing from suppliers, which occurs as follows: the company buys from a particular supplier that has long lead times, so the company needs to protect against potential parts shortages if there are unforeseen increases in its demand, therefore acquiring large batches of parts at a time, always including safety stocks. In doing so, the company has the power to negotiate discounts with the supplier due to the high volume of orders. In turn, the supplier deals with many other clients who behave in the same manner and receives many orders for large batches of parts simultaneously. The managers of the supplier factory, from a mentality based on economies of scale and cost reduction, run large batches. However, in so far as all requests for large batches of parts are placed, production cycle times increase in the supplier's factory. As the production cycle times have increased, the supplier plans for production at its factory to have longer lead times. Thus, the supplier's sales organization has to quote long lead times to the customers, which tends to worsen over time because, creating a supplier Response Time Spiral as feedback.

In QRM, it is essential that the company works with suppliers that are aware of the importance of time and seek to reduce the lead time in its operations. For this, Suri (2010a) emphasizes the importance of making suppliers understand the company QRM program, and it is up to the company to train and influence them accordingly.

3. Research Method

According to Yin (2010), the survey method is suitable when the research focuses on contemporary events and answering questions of "what" is happening or "how" and "why" it is happening; moreover, it does not require control of behavioural events. Following this approach, a survey with an exploratory characteristic was conducted to assess the degree of knowledge regarding QRM in companies from different regions of the world (Brazil, USA and Europe) that have been implementing QRM practices. The steps of this research are described in Figure 1.

<Insert Figure 1>

3.1 Hypothesis Definition

As noted earlier, despite Lean Manufacturing and QRM presenting a series of similar elements, the QRM approach presents some key elements that distinguish it from Lean Manufacturing. Many times, as highlighted by Suri (2010a), companies on the road to implementing QRM may face difficulties in implementing such elements. One possible cause for this difficulty is that companies do not perceive these elements as important. In other words, these companies do not have enough knowledge about such elements. The opposite can be said about the common elements, as Lean Manufacturing elements are already established as “world class elements” for manufacturing management. Therefore, the first hypothesis of the present study aims to investigate such question.

H0.1: Amongst companies that have been implementing QRM, the degree of knowledge of the exclusive elements of the QRM approach is lower than the degree of knowledge of elements common to both Lean Manufacturing and Quick Response Manufacturing.

The present research was performed in companies from USA, Europe and Brazil. Despite all of these companies have been implementing elements of the approach and having already been trained in the core concepts of QRM, such training and dissemination efforts are much higher in North American companies because all US companies interviewed are linked to the "QRM Center," which created such approach. Due to this proximity to the world's reference centre in the area, it follows that such enterprises shall have a degree of training and awareness greater than the others companies interviewed in Europe and Brazil. From this, arise the second hypothesis of the present study.

H0.2: The degree of knowledge of the exclusive elements of QRM is higher in companies from USA than companies in Europe and Brazil

For Suri (1998, 2010a), the scale / cost thinking is the main obstacle to the implementation of QRM. This obstacle is possibly due the fact that managers do not consider important to change their mind-set from a traditional scale/cost thinking to a lead time reduction thinking. Such statement is based on Suri´s experience, but no study found in the literature presented evidence for this argument. The third hypothesis of the present study arise from this subject

H0.3: The perceived degree of importance concerning QRM exclusive elements related to mentality based on economies of scale and cost reduction is low

3.2 Preparation of the questionnaire

To collect the data, a questionnaire developed by Hoonte (2012) was initially used for a survey conducted in Europe in 2012, aiming to develop and propose a model to measure the degree of maturity of QRM practices in enterprises. This questionnaire was used because it has been applied and tested in practice (Hoonte, 2012). To expand the search and apply it in companies in Brazil, the questionnaire that was originally developed in English was translated into Portuguese, following Chapman and Carter (1979).

After the translation, the questionnaire in Portuguese passed through three experts in QRM analysis to verify the adequacy and relevance of the terms and the accuracy to the original meaning of the questions and statements. Then, a pilot research was held with the students of the Graduate Programme in Industrial Engineering at UFSCar - Federal University of São Carlos, who are working in companies in which they apply tools and practices from QRM and Lean Manufacturing to verify the clarity and relevance of the questions for the managers.

The questionnaire is split into two sections. The first section contains open questions to gather general information about the company. The second section contains 122 closed questions or statements to assess the degree of importance attributed to them by the companies. As mentioned before, these indicators are largely based on several published questionnaires on Lean Manufacturing (Jasti and Kodali, 2015 and Marodin and Saurin, 2013; Shah and Ward, 2007; Li et al., 2005; Ketoviki and Schroeder, 2004; Nahm, et al., 2004; Cua, et al., 2001; Tu, et al., 2001; Ward, et al., 1998; Koufteros, et al., 1998, 2005), which have been extended based on QRM publications (e.g., Suri, 2010a; Suri, 1998; Godinho Filho and Saes, 2013; Riezebos, 2010). Of the 122 indicators (closed questions / statements) used, 28 refer to the QRM approach's exclusive elements (Exclusive Group), whereas the other 94 indicators refer to the common elements

(Common Group) for both approaches of QRM and Lean. Such indicators are shown in Tables 4 and 5, respectively. The evaluation of the knowledge of the QRM elements was based on the degree of importance given to them by the surveyed enterprises using a 5-point Likert scale as follows: 5 = extremely important; 4 = important; 3 = neutral; 2 = unimportant; 1 = totally unimportant. Additionally, it was possible to elect “not applicable” for every assertion.

<Insert Table 4>

<Insert Table 5a>

<Insert Table 5b>

3.3 Sample definition

The target population of this study consists of companies that have been implementing QRM’s elements in the USA, Europe and Brazil. Specifically, in the USA, to confirm or refute hypothesis 2 of this work, the target population is made up of enterprises that are linked to the Center for QRM at the University of Wisconsin - Madison.

Therefore, an intentional sample (Patton, 2002) representative of the target population was created. Among the more than 200 companies with agreements with the QRM Center (USA) and over a hundred European and Brazilian companies that have been implementing QRM, North American and European companies that presented papers at the 2013 QRM conference held by the QRM Center in Madison / USA were selected for the study. These papers presented implementation of QRM projects; thus these companies were implementing QRM. Also, Brazilian manufacturing companies that are already in the process of implementing QRM elements were selected. They were chosen based on a data base maintained by the authors of the present study about QRM implementation in Brazil. The great majority of companies within this database have their implementation supported by the authors of the present study.

Regarding the US and Europe, every company that made a presentation at the conference held in the US, from 4 to 6 June 2013, was contacted during the event. All of them agreed to participate and have set out to answer the questionnaire of the survey; business cards and an information sheet containing detailed information and a link to access the questionnaire were given to them. From these contacted companies, 12 responded to the online questionnaire, 6 companies from USA and 6 companies from Europe. From the companies consulted in Brazil, 12 agreed to participate in the survey, and the questionnaire was sent by e-mail. Of these 12 companies, 8 responded to the questionnaire. Therefore, the total sample was 20 enterprises.

Admittedly the sample size used in this study is quite limited by having worked with a possible sample from the relatively small target population of MTO manufacturing companies around the world that have been implementing QRM. The sample size in the various regions has been affected by the willingness of companies to complete and return the questionnaire. We have applied the usual techniques to increase the response rate and selected appropriate statistical methods, which has resulted in analyses and conclusions that allow relatively small sample sizes, so we feel that the study is of value for the audience of this journal.

The data analyses carried out in this research didn't have the purpose of generalization, as it is an exploratory study. Exploratory studies having no objective of generalization and using small samples are common in operations management literature. Some examples of papers of the last 3 years are: Srai and Ané (2016), Van Donk and Van Doorne (2015), Liu and Liang (2015), Chou (2014), Samson and Gloet (2014).

3.4 Collection and analysis of data

In Brazil, the survey was answered by three respondents for each company, who generally hold CEO or senior manager positions of operations / production / planning / product engineering. In European and North American companies, the questionnaire was answered by only one person from each organization, the majority of which held CEO or operations manager positions.

In order to fulfil the objectives of this research (an exploratory survey), we choose the more appropriate nonparametric statistical tests (Siegel and Castellan Jr. 1988) to each research problem, as follows:

1) Friedman test

The first research issue, in terms of data analysis, is to know the relative position of each indicator evaluated in relation to the others, looking for to identify which elements and practices of QRM are considered most and least important by the companies surveyed. So, it was necessary to build rankings with the values of degree of importance sorted from highest to lowest.

As we are working with nonparametric statistical tests, since the data were collected through an ordinal scale (Likert scale) we opted to use the logical fundaments of the Friedman test that is a nonparametric proof applicable to these situations as recommends Siegel and Castellan Jr. (1988).

Although the Friedman test is useful to carry out hypothesis testing when data of k corresponding samples present themselves in at least an ordinal scale, in our paper it was just used to build the rankings used to compare the relative position of each element/ practice of QRM. This test does not use numeric data directly, but the positions (mean rank) occupied by them after ordering each group separately (Siegel and Castellan Jr., 1988; Maroco, 2011), which meets our need without violating any statistical assumption of normality or sample size.

2) Wilcoxon-Mann-Whitney U test

The second problem to be solved by the statistical analysis of the data collected was whether the degree of importance attributed by firms surveyed to a group of particular elements of QRM is lower than the level assigned to the group of common elements to QRM and Lean.

For this, we applied the Wilcoxon-Mann-Whitney U-test, which checks whether there is evidence to believe that the values of a group A are higher than those in group B. The U test can be considered a nonparametric version of the t-test for independent samples. Unlike the t-test, which tests the equality of means, Mann-Whitney test (U) tests the equality of medians (Siegel and Castellan Jr., 1988; Maroco, 2011).

As we are working with independent distributions of medians, meet up all testing assumptions.

3) Kruskal-Wallis test

Another issue of interest to be clarified with the statistical analyses in the research was to determine whether the different degrees of importance attributed to each indicator by the companies surveyed actually suggest differences between populations (regions studied) or are just random variations that can be expected random samples from the same population.

The Kruskal-Wallis test is a nonparametric test used to compare three or more independent samples (Siegel and Castellan Jr., 1988; Maroco, 2011). It tells us if there is a difference between at least two of them.

To be used, this test requires the following conditions (Siegel and Castellan Jr., 1988) for its proper use:

1. It must be used to compare three or more independent samples;
2. The minimum size of each sample should be 6;
3. Data which level measurement is at least ordinal;
4. The data can be sorted and to which you can assign jobs or orders;
5. It cannot be used to test differences in a single sample measured more than once respondents;

Considering that in this research we worked with three independent samples (Brazil, Europe, and the USA) with respectively, n = 8, n = 6 n = 6, the data is on an ordinal scale, and are liable to be sorted in orders, with respondents (companies) measured once in each indicator, we can say that the assumptions for the use of Kruskal-Wallis test are met.

4. Results

4.1 Comparison between the degree of QRM exclusive elements' knowledge and the elements common to other management approaches

Having the answers from the surveyed enterprises, the Friedman test was applied, and a ranking was elaborated according to the degree of importance assigned to each indicator (closed question / statement), ordering the results (mean rank values) in descending order, by which it is possible to observe the relative position of each indicator in relation to the others. Table 6 summarizes the indicators that occupy the highest positions (Top 10%) and lowest positions (Bottom 10%) in the importance ranking.

First of all, the concentration of indicators for the exclusive elements of the QRM (hatched in grey) is clearly seen in the final part of the table. It is observed that in the initial part of the table, among the 12 (10%) indicators considered most important by the companies surveyed, only 3 belongs to the group of exclusive elements of QRM. In contrast, 7 indicators of exclusive elements of QRM are among the 12 least important in the final part of the table (below the central value of the ranking).

As a general rule, these results show that managers of the companies researched attribute less importance to several QRM-specific elements. Some of these elements focus on delivery accuracy, which relates to lead time performance, but according to QRM theory it might be counter effective to aim for delivery accuracy instead of short lead times. As mentioned before, the enterprises are aiming to reduce the lead time. Therefore, the allocation of low importance to the QRM's exclusive elements by companies with these characteristics leads to the conclusion that managers in such companies do not even know a number of principles and / or ways to reduce lead time. These results are similar to those obtained when using the ranking by average.

<Insert Table 6.>

Table 7 shows the descriptive statistics and the degree of importance assigned by the companies surveyed to the Exclusive Group (QRM's exclusive elements) and to the Common Group (elements common to QRM and Lean Manufacturing) in each region, from which it can be noted that the importance given to Exclusive Group is lower than the importance attributed to Common Group in all regions studied, except in the USA.

<Insert Table 7.>

Looking to the overall sample of enterprises studied, the results of the non-parametric Wilcoxon-Mann-Whitney U test (Table 8) demonstrate that there are statistically significant differences between the scores obtained by the indicators of

Exclusive Group and the Common Group (p-value <0.05), thereby confirming that the importance assigned to the exclusive elements of QRM is lower than the importance given to the elements QRM has in common with Lean Manufacturing.

<Insert Table 8.>

These results show that there is a lack of knowledge of the practices to be implemented to reduce the lead time in the studied companies. Therefore, the hypothesis H0.1 (the degree of knowledge of the exclusive elements of the QRM approach is lower than the degree of knowledge of elements common to Lean Manufacturing and Quick Response Manufacturing) is accepted.

The results shown in the Table 7 indicate yet that the distance between the investigated groups among the companies in the United States is lower than in Brazil and Europe, possibly because the degree of awareness of QRM's exclusive elements is higher in the US than in Brazil and Europe. This higher awareness in the US is probably because QRM arose in the US, which makes the degree of knowledge, dissemination, training and awareness of such approach in this country more extended than in Brazil and Europe, because of the QRM dissemination actions as well as training and awareness promoted in that country. As a result, hypothesis H0.2, which states that the degree of knowledge of QRM's exclusive elements is higher in companies from USA than companies from Europe and Brazil is also accepted.

4.2 Evaluation of the knowledge regarding the QRM approach's exclusive elements

In this section, the degree of knowledge of each of the 28 exclusive elements of the QRM approach, grouped into each of the three core concepts of QRM as shown in section 2.2, is evaluated.

4.2.1 Knowledge of the exclusive elements concerning core principle # 1: The Power of Time

As shown in section 2.2, the core concept “The Power of Time” includes two exclusive elements of QRM: (i) unlike the Lean Manufacturing, which seeks to reduce costs and inventories through the elimination of all waste throughout the production process of the company, the core goal of QRM is reducing lead time in all operational aspects of the organization; and (ii) the reduction of lead time should be the main performance measure.

Regarding the total focus on reducing lead time, it is evident that the companies attempt to reduce WIP levels (EX02) and lead time (EX05, EX07, EX11, EX12 and EX13) as recommended by the QRM, but Table 9 draws attention to the fact that a key QRM element (EX03), – not using cost as the main performance evaluation criterion, is considered unimportant for the companies surveyed. This fact demonstrates how much the companies surveyed are still linked to economies of scale and the cost reduction paradigm. Therefore, these results clearly show the difficulty faced by enterprises, even those seeking by free initiative to reduce lead time, to replace the cost by lead time as the main performance indicator. Table 10 shows that this conclusion is basically the same for all three regions analysed.

<Insert Table 9.>

<Insert Table 10.>

Concerning the adoption of lead time as a primary performance measure, it is observed in Table 11 that the companies surveyed, although they consider important to use the lead time as a performance evaluation criterion (EX09), in contrast to what the QRM advocates, they also consider on-time delivery as a primary driver of performance improvement efforts (EX06 and EX08). The employees in these companies are measured by punctuality of delivery and not reduction of lead time (EX26).

Thus, one can conclude that the surveyed companies are still generally reluctant to adopt lead time as the main guideline for their strategies and decisions. From these results, it is concluded that this reluctance is due to lack of understanding, on the part of the companies surveyed, that the on-time delivery being a measure of performance constitutes an incentive for managers to inflate the deadlines planned in all areas of the company, institutionalizing long lead times in the company (Suri, 2010a) and leading to dysfunctional ripple effects (Response Time Spiral).

It is also observed in these companies that product quality / reliability is another performance metric considered extremely important (EX10). What shows again the difficulty faced by enterprises to replace the use of traditional metrics based on quality, cost and delivery time by lead time as the main performance indicator, even those give importance to reduce lead time. This probably is because of on-time delivery and quality are performance criteria used by Lean, which is an approach that has been published and disseminated among the companies for much longer than the QRM.

Godinho Filho and Veloso Saes (2013) show that the most important and common point to all research within the QRM approach is the focus on reducing lead time and the corresponding amendment of the company's performance indicators. This research presents information about companies that face great difficulty related to such element vital to QRM. The values in Table 12 show that this conclusion is valid for the three regions surveyed.

<Insert Table 11.>

<Insert Table 12.>

4.2.2 Knowledge of the exclusive elements relating to core concept # 3: Understanding and Exploiting System Dynamics

As defined in section 2.2, core concept #3, “Understanding and Exploiting System Dynamics,” encompasses three exclusive elements of QRM: (i) recognition of the strategic variability; (ii) mitigating the effects of variability while maintaining the use of only 70% to 80% of the installed capacity; and (iii) use of the POLCA system.

Concerning the strategic variability, the results in Table 13 show that in most cases, the surveyed companies consider it very important to eliminate bad variability in their processes (EX28), as recommended in Lean Manufacturing, but consider it also very important to recognize and attempt to exploit strategic variability that related to providing a variety of products for customers (EX27). Based on these results, it can be concluded that the companies surveyed are aware of and understand this exclusive concept of QRM. It is observed in Table 14 that this conclusion concerning the recognition of strategic variability is valid for the three regions surveyed and that the companies surveyed in Europe are indifferent to the elimination of bad variability from the process, unlike the companies surveyed in the other countries studied.

<Insert Table 13.>

<Insert Table 14.>

Regarding the ways to mitigate the effects of variability observed in Table 15, only three indicators (EX22, EX23 and EX24) were considered important or very important. The majority of companies surveyed consider the strategy of having spare capacity as a buffer to mitigate the effects of variability (EX24) to be important. Moreover, they seek to gain flexibility and agility rather than maximizing the use of resources installed (EX22) and attempting to work with short and accurate planning horizons (EX23). Nevertheless, in contrast to the recommendation of the QRM approach, the surveyed companies are generally indifferent to the non-prioritization of the use of the total plant capacity (EX01), and they consider the productivity being the main performance evaluation criterion (EX04) to be important. This instance illustrates how deeply rooted the belief that for faster completion of work, it is necessary to keep the machines and people busy constantly is in the mentality of production managers and how possibly unaware of the dysfunctional manufacturing effects caused by such belief they are. The importance assigned to productivity-based metrics is further evidence of the difficulty faced by companies in adopting new ways to compete, other than those based on the paradigm of efficiency (cost), represented by the maximum use of resources, even in companies that seek to reduce the lead time.

Considering the analysis carried out by region, shown in Table 16, it is seen that most of these findings are valid for the three regions studied. It is noteworthy that the issue of not maximizing the use of resources (EX01) and non-use productivity as the main performance evaluation criteria (EX4) is even less understood in Brazil, given the low degree of importance assigned by the companies surveyed. It is observed also that working with a short and precise horizon of production planning (EX23) and seeking gains in flexibility and agility rather than maximizing the use of machines and people (EX22) are concepts more established among North American enterprises, for which the lowest score attributed to these indicators was 5 (very important). From this, it was concluded that the exclusive elements of QRM regarding ways to mitigate the effects of variability appear to be better disseminated in the US companies and less in Brazilian companies.

<Insert Table 15.>

<Insert Table 16.>

Regarding the use of the POLCA system, it follows that the surveyed companies consider it important to carry out the control of production in QRM cells using a hybrid system that pulls and pushes the production, combining the characteristics of MRP and Kanban systems, as shown in Table 17. Thus, it can be realized that the degree of knowledge of the tools of POLCA, is wide for the surveyed companies, which probably already had problems trying to use a pure pulled (Kanban) or pure pushed (MRP) system in their production environments, characterized by demand for products with a high degree of variety / customization and the market demanding short lead times. Comparing the degrees of importance given by companies surveyed in each country, it is seen in Table 18 that the situation is almost the same in the three regions studied. This element, however, seems to be more consolidated among the US companies because the variability of responses between them is smaller than in other regions.

<Insert Table 17.>

<Insert Table 18.>

4.2.3 Level of knowledge of the QRM approach regarding core concept #4: Enterprise-wide application

Core concept #4, “Enterprise-wide application,” comprises a series of QRM’s exclusive elements related to supplier policy, which should be based on lead time. In Table 19, the companies surveyed generally judge as important the elements concerning suppliers recommended by QRM, such as: have suppliers be aware of the importance of the power of time and seek to reduce their lead times (EX18); consider the delivery time as a criterion for selecting suppliers (EX20); work with low inventories due to short lead times from suppliers (EX19); have critical suppliers located in close proximity to the plant (EX14); and train suppliers to reduce their lead time (EX16). They also state that in some cases, they are willing to pay more to suppliers with shorter delivery times (EX21).

In contrast, the surveyed companies consider it unimportant to not work with large lots (EX15), which is a common practice of economies of scale and cost-based mentality (Suri, 2010a). They also believe it to be neutral to work with smaller suppliers to influence them to reduce their lead time (EX17). It is concluded that it is still difficult for companies to understand some elements for reducing the lead time related to the supply chain, especially regarding not working with quantity discounts, which leads to large lots, and having smaller suppliers (EX15), because, as is the case for some of QRM's other elements, the mentality based on cost is apparently still the major obstacle to reducing the lead time in the supply chain of the companies studied.

<Insert Table 19.>

As is presented in Table 20, comparing the regions, it is observed that understanding QRM's elements that discourage the adoption of the practice of gain quantum discount to avoid receiving infrequent shipments of large quantities (EX15) and deal with smaller companies (EX17) is of great difficulty for the companies surveyed in the three regions studied. Regarding the other elements, it can be observed that European companies, compared to Brazilian and North American companies, have more difficulty understanding the elements regarding the supply chain, such as: suppliers should be aware of the importance of lead time (EX18); the importance of working with suppliers with short delivery times (EX19); training suppliers (EX16); and having suppliers with geographically close locations to the company (EX14). This might be due the characteristics of the European companies that participated in the survey – most of them are make-to-order companies with general available raw materials.

<Insert Table 20.>

5. Conclusions

The first important result of the present work was to show that the surveyed companies, even those in the midst of the QRM implementation process, still have difficulty knowing and understanding some elements exclusive to this approach. Actually, in general, the degree of knowledge regarding QRM in these companies was markedly lower than knowledge of the elements of Lean Manufacturing. On one hand, this result was expected because the elements of what is now called Lean Manufacturing were formulated in the 1950s and have been disseminated among companies in the West since the late 1970s, whereas the QRM approach emerged in only the late 1990s. On the other hand, it was also expected that companies in the implementation process of QRM would utilize its elements in full. The present study showed that that is not occurring. This is an important finding for industrial engineers and managers responsible for implementing QRM. They should not underestimate the knowledge gap within companies that have chosen to start the QRM journey and invest in training employees from all layers and functions within the company in QRM elements so that they buy into and support the company-wide implementation.

In the literature, there is no study comparing the knowledge degree of Lean Manufacturing and QRM. Some studies have come close to this question, for example Garza-Reyes et al. (2015), which concluded that knowledge of operation improvement methods (QRM, Lean, TOC, Six Sigma) in the engineering sector in Greece was generally very limited or non-existent. The results of our study contribute to filling this gap.

An analysis by region showed that there are statistically significant differences (p-value < 0.05) between the knowledge degree of QRM's exclusive elements and that of elements common to Lean and QRM in the companies surveyed in all regions studied. It was noted as well that the values of the mean and median knowledge degrees of QRM's exclusive elements in the companies surveyed in the USA are higher than those of the companies surveyed in other regions. This difference is probably because QRM arose in the USA, where the dissemination, training, and awareness probably contribute to make the knowledge degree regarding such approach greater than in other studied regions. This result is consistent with several studies in the literature that address the issue of university-industry collaboration as a way to increase the benefits and advantages that companies gain by implementing improvements developed in academia (Philbin 2012; Woll 2011).

We consider this study as a first explorative step to enhance the implementation of QRM. Further elaborated methodologies and actions could create solid effects by providing the knowledge of “how to do it”. A more detailed analysis regarding the exclusive elements in the core concepts of QRM shows the following:

Regarding core concept #1, "The Power of Time," it was observed that for the companies surveyed, although they consider it important to have lead time as the primary measure of performance, they generally continue to associate cost as the primary measure performance. In addition, the results showed that even companies that wish to reduce their response times focus their efforts on delivering products on time and not on lead time reduction.

Referring to core concept # 3, "Understanding and Exploiting System Dynamics," the results showed that companies consider it important to both explore strategic variability and eliminate bad variability caused by the lack of standardization and inadequate management of production processes. Therefore, that exclusive element of QRM is already well understood by the surveyed companies. Regarding ways to mitigate the variability, the results show that the surveyed companies generally face difficulties in adopting a new way to compete, based on time, and release itself of productivity metrics, indicating that the mentality based on economies of scale and cost reduction is deeply rooted in the mentality of production managers and is the main obstacle to the incorporation of new knowledge, even in companies that seek to reduce the lead time. Metrics such as productivity and capacity utilization continue to drive efforts in the surveyed companies. Suri (1998, 2010a) emphatically states this difficulty. Nevertheless, it was hoped that this difficulty would be lessened through training, dissemination and awareness. It is understood, however, that such obstacles remain for these companies despite the wish to reduce the lead time and understand the QRM approach. Based on the analysis by region, it is possible to comprehend, however, that this issue is better understood by the companies surveyed in the US than by the companies surveyed in Brazil and Europe. This finding again shows the positive effect of the university-industry interaction that occurs between the Center for QRM and companies from the USA. Concerning production planning and control, the results show that the surveyed companies consider it important that QRM cells use a hybrid production control system that combine characteristics of MRP and Kanban.

Regarding the application of QRM concepts in the supply chain, it is observed that despite the surveyed companies generally considering the elements concerning the suppliers to be important, they have not abandoned the practice of buying large lots for discounts due to the amount and quantity and that they also believe that working with smaller suppliers to influence them to reduce their lead times and train them accordingly is unimportant. This observation is evidence that it is still difficult for companies to fully understand the elements recommended by QRM regarding suppliers. Again, it is seen that the cost/productivity-based mentality seems to be a major obstacle to reducing the lead time in the supply chain of the companies studied. For QRM, such a mentality may be counterproductive if a company has to compete on time and has to reduce its lead time. Market circumstances may be such that shorter lead times might make it possible to be an attractive supplier and even allow some slightly higher operational costs, as the company is more responsive to the dynamic markets of their customers. Lead time reduction is seen as a strategy that involves reduction of overhead activities, waiting time, waste, and in the end to a better market position. However, a direct focus on cost reduction and due date adherence is, according to the QRM philosophy, a root cause for problems.

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Table 1. Elements associated with the Lean Manufacturing approach.

Item	Element	Brief description
1	Automation (Jidoka)	It consists of the idea of automation with human intelligence, seeking to get to the equipment the ability to distinguish good parts from bad ones without monitoring an operator.
2	Cellular layout	A physical arrangement where the machines are grouped into manufacturing cells to produce families of parts or products.
3	Concurrent engineering / simultaneous engineering	Concurrent engineering is a method of designing and developing products, in which the different stages run simultaneously, rather than consecutively.
4	Continuous flow	The strategy of produce and move one item at a time (or a small batch of items) along a series of processing steps continuously, and in each step is performed only what is required by the next step.
5	Customer involvement	The customer should be involved since the early stages of designs and product development.
6	Design for manufacturability	A method of design for ease of manufacturing of the collection of parts that will form the product after assembly.
7	Elimination of waste	Waste is considered anything in the production process that does not add value to the customer and because of this should be continuously identified and eliminated.
8	Employee commitment	The employees' commitment and involvement is fundamental to lean activity, that requires production process analysis and the continuous identification and elimination of waste.
9	Feedback of performance metrics	Give feedback of performance metrics to the workers to track and encourage them toward the critical goals of the organization
10	Flexible information system	The information flows should be simplified by establishing unique points of production scheduling and pulled loops of information between previous processes until to the production starting point.
11	Housekeeping (5S)	Five related terms, starting with the letter S, which describes practices for the workplace.
12	JIT production	Production system that produces and delivers only the necessary required quantity, when needed.
13	JIT purchasing	Procurement system in which the suppliers delivers only the necessary, when needed and in the required quantity.
14	Kaizen	A strategy where employees work together proactively to achieve regular, incremental improvements in the manufacturing process.
15	Kanban	A method for flow of goods regulation based on automatic replenishment through signal cards.
16	Long-term supplier and customer relationship	In running both Lean or QRM practices it's essential building long-term supplier and customer relationships.
17	Multifunctional employees	The employees must be trained (cross-training) to perform multiple tasks.
18	Pull production	Manufacturing system based on actual demand, in which the production operations start triggered by actual demand assigned to later processes.
19	Quality at the source	In a practical sense, it would involve each operator checking his or her own work before the part/component or product is sent to the next step in the process.
20	Root cause analysis for problem solving	A problem-solving methodology that focuses on removing the actual problem's causes instead of mitigate the immediate symptoms of the problem.
21	Set-up time reduction	Reducing the time required to change production from one product to another in a given machine or in a series of interconnected machines.
22	Small lot size	The Lean predicts that production will be made in small batches and if possible in batches of one part.
23	Standardization of work	The establishment of precise procedures for the work of each operator in a production process.
24	Statistical process control (SPC)	SPC is an industry-standard methodology for measuring and controlling quality during the manufacturing process based on the capability of the process.
25	Supplier involvement	The suppliers must be involved since the early stages of design and product development.
26	Takt time	Used to synchronize accurately production with demand giving rhythm to lean production system, is the time available for the production divided by customer demand.
27	Teamwork	Instead of managers or supervisors controlling departments, cells teams manage themselves.
28	Top management commitment	The involvement and the explicit support of the top management are fundamental to running programs that involve culture change.
29	Total productive maintenance	Technique that involves the operators themselves in daily maintenance activities, in machines improvement projects and simple equipment repairs.
30	Total quality management	A management approach based on customer satisfaction in which all members of an organization participate in improving processes, products and services.
31	Uniform work load	A form of production scheduling that purposely produces in smaller batches by sequencing and mixing product variants within the same process.
32	Value stream mapping	Simple diagram of all the steps involved in the flows of materials and information needed to serve customers, from order to delivery.
33	Visual factory communication	Visual indicators, displays and controls used throughout manufacturing plants to improve communication of information.
34	Workforce autonomy	The cells teams should have complete autonomy over the work and have ownership of the entire delivery process within their cells.
35	Workforce effort recognition and reward	According to the lean philosophy the workers' effort should be recognized and rewarded to motivate them.

Table 2. Key principles of QRM.

Number	Principle	Quick Overview
1	Find whole new ways of completing a job, with a primary focus on minimizing lead time	Taking time out of the system requires completely rethink how production, materials supply and work management is organized.
2	Plan to operate at 80 percent or even 70 percent capacity on critical resources.	The QRM recommends that one should seek gain in flexibility and agility rather than maximize the use of equipment and personnel.
3	Measure the reduction of lead time and make this the main performance measure.	In this new way of managing the manufacturing, the reduction of lead time should be the main performance measure.
4	Stick to measuring and rewarding reduction of lead times.	The improvement of the traditional indicators will be consequence of this strategy focused on time.
5	Use the MRP (Material Requirements Planning) only at the highest levels of production planning and materials	The QRM recommends the use of a hybrid production control system specially designed for QRM cells, called POLCA, that combines features of MRP and Kanban.
6	Motivate suppliers to implement QRM.	It is essential that the company works with suppliers aware of the importance of time and seeking to reduce the lead time on its operations.
7	Educate customers about your QRM program, and negotiate a schedule of moving to smaller lot size at reasonable prices	It is necessary to demonstrate to the client how the QRM will allow them to receive in small batches, rapidly without increasing prices.
8	Eliminate functional barriers by forming Quick Response Office Cell (Q-ROC)	The QRM recommends the use of cells also in the office's operations, not only in the shop floor.
9	Make it clear to everyone in the organization the correct purpose of the QRM program	The true reason for the QRM’s adoption is to make the company competitive in the long run through the time-based competition.
10	The biggest obstacle to QRM is not technology, but the mentality based on costs and efficiency.	The shift from a mindset based on efficiency and cost to a mentality based on lead time reduction only occurs through training and awareness.

Table 3. Common elements for Lean and QRM.

Item	Element	Brief description
1	Cellular layout	A physical arrangement where the machines are grouped into manufacturing cells to produce families of parts or products.
2	Concurrent engineering / simultaneous engineering	Concurrent engineering is a method of designing and developing products, in which the different stages run simultaneously, rather than consecutively.
3	Design for manufacturability	A method of design for ease of manufacturing of the collection of parts that will form the product after assembly
4	Multifunctional employees	The employees must be trained (cross-training) to perform multiple tasks.
5	Root cause analysis for problem solving	A problem-solving methodology that focuses on removing the actual problem’s causes instead of mitigate the immediate symptoms of the problem.
6	Teamwork	Instead of managers or supervisors controlling departments, cells teams manage themselves.
7	Workforce autonomy / empowerment	The cells teams should have complete autonomy over the work and have ownership of the entire delivery process within their cells.
8	Workforce recognition/ reward	According to the QRM and the lean philosophy the workers’ effort should be recognized and rewarded to motivate them.

Figure 1. Steps of the research.

Step #1	**Step #2**	**Step #3**	**Step #4**
Definition of hypothesis	Preparation of the research instrument	Sample definition	Collection and analysis of data
1.1. Definition of variables 1.2. Identification of relations 1.3. Formalization of hypothesis	2.1. Questionnaire review 2.2. Pilot test 2.3. Upload the questionnaire in the internet	3.1. Population's identification 3.2. Definition of the sample 3.3. Sending the questionnaire / link	4.1. Return of completed questionnaires 4.2. Data tabulation 4.3. Statistical treatment and data analysis 4.4. Finds and results interpretation

Table 4. Indicators concerning the elements exclusive to the QRM approach.

Code	**Indicators**
EX01	Full capacity utilization is not one of our management priorities in manufacturing
EX02	Reducing inventory is one of our management priorities in manufacturing
EX03	We do not use cost as criterion in evaluating line managers’ performance
EX04	We do not use productivity as criterion in evaluating line managers’ performance
EX05	We have a short delivery time
EX06	We deliver on due date
EX07	We continuously reduce production lead time
EX08	On-time delivery is not a performance evaluation criterion
EX09	We use production cycle time as a criterion in evaluating line managers’ performance
EX10	We deliver a high product quality performance/reliability
EX11	We are able to quickly introduce a new-product
EX12	We are implementing actions to reduce the lead time at design department
EX13	We are implementing improvement actions at the shop-floor driven by the lead time reduction.
EX14	Our key suppliers are located in close proximity to our plants
EX15	We do not adopt the practice of gain quantum discount to avoid to receive infrequent shipping of large quantities
EX16	We train suppliers to improve lead time reduction
EX17	We seek to work with smaller suppliers in order to influence them towards the reduction of lead time
EX18	Our suppliers are aware of the power of time
EX19	We are able to work without stocks, due to the short delivery time(s) of our supplier(s)
EX20	We consider delivery time as crucial criterion in selecting suppliers
EX21	In some cases, we are willing to pay more for a supplier with a shorter delivery time
EX22	We do not aim for maximum utilization, so that we gain flexibility/robustness
EX23	We work with a short and accurate planning horizon
EX24	You can buffer variability on three ways: time, capacity and inventory. Our buffers exist mainly of idle capacity, which enables us to have little till no inventory and quicker response
EX25	Production at a workstation starts only when both authorization, material and capacity at the required workstations are available
EX26	Employees are charged by lead time rather than delivery time
EX27	We recognize strategic variability and try to exploit it
EX28	We eliminate bad variability out of our process

Source: Adapted from Hoonte (2012)

Table 5a. Indicators regarding the common elements of the Lean and QRM approaches.

Code	Indicators
CM01	Production cost is not is not a manufacturing management priority.
CM02	Labour productivity is not is not a manufacturing management priority.
CM03	We offer a large number of product features or options
CM04	We are able to rapidly adjust the capacity
CM05	We have the ability to make design changes
CM06	We deliver a high product durability/lifetime
CM07	We are able to rapidly solve customer complaints
CM08	Conformance to design specifications is one of our management priorities in manufacturing
CM09	We are implementing actions to reduce the lead time in the engineering department
CM10	We are implementing actions to reduce the lead time in the financial department
CM11	We are implementing actions to reduce the lead time in the purchasing department
CM12	We are implementing actions to reduce the lead time in the P&D department
CM13	We are implementing actions to reduce the lead time in the sale department
CM14	We have written rules and procedures that show how workers can make suggestions
CM15	Our workers have their own space and time to experiment with their job
CM16	We have written rules and procedures that guide quality improving and creative problem solving
CM17	Our workers have the authority to correct problems when they occur
CM18	Our work teams have control over their job
CM19	Our supervisors or middle managers are supportive of the decisions made by our work teams
CM20	We encourage workers to be creative in dealing with problems at work
CM21	There are few layers in our organizational hierarchy (less than four)
CM22	Our tasks are done through cross-functional teams
CM23	Our managers are assigned to lead various cross-functional teams
CM24	In our organization employees receive training to perform multiple tasks
CM25	In our organization employees are cross-trained so that they can take over tasks from other employees if necessary
CM26	In our organization, the workers are specialized and learn to perform a few or only one job / task.
CM27	Communications are carried out among managers frequently
CM28	Communications are easily carried out among workers
CM29	Strategic decisions are quickly passed on to relevant work groups
CM30	Communication between different levels in hierarchy is easy
CM31	Workers can easily meet and communicate with upper management
CM32	We are frequently in close contact with our customers/users
CM33	We strive to be highly responsive to our customers' /users' needs
CM34	We share our forecast/demand information with the customer(s)
CM35	We share our forecast/demand information with the supplier(s)
CM36	We frequently are in close contact with our suppliers
CM37	We receive parts from suppliers on time
CM38	We receive the correct number of parts from suppliers
CM39	We receive high quality parts from suppliers
CM40	We receive the correct type of parts from suppliers
CM41	We receive small-quantity frequent deliveries from our suppliers
CM42	We are aware of the suppliers lead times
CM43	Our suppliers have a short delivery time
CM44	Products are classified into groups with similar processing or routing requirements
CM45	Our processes are located close together so that material handling and part storage are minimized
CM46	Families of products determine our factory layout
CM47	Equipment is grouped to produce families of products

Source: Adapted from Hoonte (2012)

Table 5b. Indicators regarding the common elements of the Lean and QRM approaches.

Code	Indicators
CM48	Shop-floor employees lead product/process improvement efforts
CM49	Shop-floor employees drive suggestion programs
CM50	During problem solving sessions, we make an effort to get all team members' opinions and ideas before making a decision
CM51	Shop-floor employees are key to problem solving teams
CM52	We created our own tools to improve lead time reductions
CM53	Production at stations is "pulled" by the current demand or available capacity of the next stations
CM54	Our production system enables us to reduce the work on the shop floor
CM55	We use a production planning system, but only to authorize /control the first workstation of the production line
CM56	We use a "pull" or combinations of "push" and "pull" production system
CM57	Production is "pulled" by the shipment of finished goods
CM58	Production is "pulled" by visual/virtual cards or bins
CM59	We can handle "rush orders" without disturbing our average delivery time
CM60	Charts plotting the frequency of machine breakdowns are posted on the shop floor
CM61	Information on quality performance is readily available to employees
CM62	We use fishbone type diagrams to identify causes of quality problems
CM63	Charts showing defect rates are posted on the shop floor
CM64	We maintain all our equipment regularly
CM65	We maintain excellent records of all equipment maintenance related activities
CM66	We post equipment maintenance records on the shop floor for active sharing with employees
CM67	We emphasize good preventive maintenance
CM68	We dedicate a portion of everyday to planned equipment maintenance activities
CM69	Our operators perform certain equipment maintenance activities (such as lubricating, cleaning machine parts)
CM70	We are working to lower set-up times in our plant
CM71	We reduced the set-up times of equipment in our plant to the minimum
CM72	Short set-up times enables us to use relative small batch sizes
CM73	Our crews practice set-ups to reduce the time required
CM74	Product development / engineering activities are parallelized (performing tasks con
CM75	Various disciplines are involved / integrated in product development / engineering
CM76	We apply tools and techniques that will shorten or integrate steps
CM77	We visit / listen to our customers to discuss product development / engineering issues
CM78	Our customers / users are actively involved in the product design process
CM79	Customer experience our time-to-market as quickly
CM80	During development / engineering we are still able to execute customer's feedback
CM81	We have rapid prototyping techniques
CM82	We use tools and techniques to cut decision-making time
CM83	We follow an upfront planning and phased development plan (stage-gate model)
CM84	Our (new) product development / engineering process is flexible so that we can quickly response to customer specific product wishes
CM85	During development / engineering we have the ability to make changes, without being too disruptive
CM86	We measure time-to-market from the last change in requirements until the product is delivered
CM87	Our suppliers develop component parts for us
CM88	Our suppliers are involved in the early stages of product development / engineering
CM89	We make use of supplier expertise in the development / engineering of our product
CM90	Our customers give us feedback about our quality and delivery performance
CM91	We regularly survey our customer's / users' requirements
CM92	We encourage our customers to place frequently low volume orders
CM93	We have a maximum customer's compliance service rate
CM94	Our customers experience short lead times

Source: Adapted from Hoonte (2012)

Table 6. Indicators that are considered more and less important.

Code	Practices	Average	Median	Minimum score	Maximum score	*Mean Rank*	*Ranking position*
EX13	We implement improvement actions in the shop floor driven by the *lead time* reduction.	4,85	5,00	3	5	85,70	1
EX10	The company focuses more its efforts to reduce lead time than to the production of high quality and reliable products	4,95	5,00	4	5	85,53	2
CM37	We receive the correct number of parts from suppliers	4,85	5,00	2	5	85,03	3
CM38	We receive high quality parts from suppliers	4,85	5,00	2	5	85,03	3
CM06	We are able to rapidly solve customer complaints	4,88	5,00	3	5	84,60	5
EX06	We delivery on due date	4,93	5,00	4	5	83,75	6
CM32	We strive to be highly responsive to our customers/users' needs	4,84	5,00	2	5	83,05	7
CM36	We receive parts from suppliers on time	4,83	5,00	2	5	82,55	8
CM39	We receive the correct type of parts from suppliers	4,80	5,00	2	5	82,18	9
CM64	We maintain all our equipment regularly	4,85	5,00	4	5	81,98	10
CM31	We are frequently in close contact with our customers/users	4,74	5,00	2	5	80,03	11
CM91	Our customers give us feedback about our quality and delivery performance	4,68	5,00	2	5	77,78	12
							. . .
CM66	We post equipment maintenance records on the shop floor for active sharing with employees	3,45	4,00	1	5	43,63	111
CM89	Our suppliers are involved in the early stages of product development / engineering	3,70	4,00	1	5	41,28	112
CM62	We use fishbone type diagrams to identify causes of quality problems	3,70	4,00	1	5	40,50	113
CM73	Our crews practice set-ups to reduce the time required	3,60	4,00	1	5	40,23	114
EX17	We seek to work with smaller suppliers in order to influence them towards the reduction of lead time	3,10	3,00	1	5	32,25	115
EX01	Full plant capacity utilization is not a manufacturing management priority.	2,83	3,00	1	5	31,80	116
EX04	Productivity is not the main performance evaluation criterion	2,23	2,00	1	5	21,45	117
EX26	Employees are charged by lead time rather than delivery time	1,85	1,00	1	5	18,38	118
EX03	Cost is not the main performance evaluation criterion	2,18	2,00	1	4	18,03	119
CM25	In our organization, the workers are specialized and learn to perform a few or only one job / task.	2,18	2,00	1	5	14,90	120
EX15	We do not adopt the practice of gain quantum discount to avoid to receive infrequent shipping of large quantities	2,33	2,75	1	5	14,90	120
EX08	On-time delivery is not a performance evaluation criterion	1,73	1,00	1	5	13,83	122

Table 7. Comparison of importance level between indicator groups.

Region	Exclusive Group		Common Group	
	Average	**Median**	Average	**Median**
BRA	3,80	**4,00**	4,66	**5,00**
EURO	3,75	**4,00**	4,06	**4,50**
USA	4,27	**5,00**	4,78	**5,00**

Table 8. Results of the Wilcoxon-Mann-Whitney U test.

Statistic	Results*
Mann-Whitney U	895,000
Wilcoxon W	1301,000
Z	-2,931
p-value	0,003

*Grouping variable: Group

Table 9. Evaluation of indicators concerning the exclusive element of QRM: management focused on reducing the lead time.

Code	**Indicators**	**Median**	**Rating**
EX07	We continuously reduce production lead time	**5,00**	Extremely important
EX13	We implement improvement actions in the shop floor driven by the lead time reduction.	**5,00**	Extremely important
EX12	We are implementing actions to reduce lead time at design department	**5,00**	Extremely important
EX11	We are able to quickly introduce a new product	**4,75**	Important
EX05	We have a short lead time	**5,00**	Extremely important
EX03	Cost is not the main performance evaluation criterion.	**2,00**	Unimportant
EX02	Inventory reduction is a manufacturing management priority.	**5,00**	Extremely important

Table 10. Comparison between regions regarding the QRM approach: management focused on reducing the lead time.

Code	**BRA**				**EURO**				**USA**			
	Median	Min	Max	Rating	**Median**	Min	Max	Rating	**Median**	Min	Max	Rating
EX07	**5,00**	4	5	Extremely important	**5,00**	3	5	Extremely important	**5,00**	3	5	Extremely important
EX13	**4,75**	3	5	Important	**4,50**	3	5	Important	**5,00**	4	5	Extremely important
EX12	**5,00**	4	5	Extremely important	**5,00**	3	5	Extremely important	**5,00**	5	5	Extremely important
EX11	**4,75**	4	5	Important	**4,50**	3	5	Important	**4,50**	4	5	Important
EX05	**4,25**	4	5	Important	**5,00**	4	5	Extremely important	**5,00**	4	5	Extremely important
EX03	**1,00**	1	5	Totally unimportant	**3,50**	1	4	Neutral	**3,00**	1	3	Neutral
EX02	**4,75**	4	5	Important	**4,50**	1	5	Important	**5,00**	3	5	Extremely important

Table 11. Evaluation of indicators concerning the QRM approach: make lead time reduction the main performance measures

Code	Indicators	Median	Rating
EX09	Production lead time is a performance evaluation criterion.	**4,00**	Important
EX06	We delivery on due date.	**5,00**	Extremely important
EX26	Employees are charged by lead time rather than delivery time.	**1,00**	Totally unimportant
EX08	On-time delivery is not a performance evaluation criterion.	**1,00**	Totally unimportant
EX10	We deliver a high product quality performance/reliability	**5,00**	Extremely important

Table 12. Comparison between regions regarding the QRM approach: make lead time reduction the main performance measure.

Code	BRA				EURO				USA			
	Median	Min	Max	Rating	**Median**	Min	Max	Rating	**Median**	Min	Max	Rating
EX09	**4,00**	3	5	Important	**3,00**	1	5	Neutral	**4,50**	3	5	Important
EX06	**5,00**	5	5	Extremely important	**5,00**	4	5	Extremely important	**5,00**	5	5	Extremely important
EX26	**1,50**	1	3	Totally unimportant	**2,50**	1	5	Unimportant	**1,00**	1	1	Totally unimportant
EX08	**1,25**	1	2	Totally unimportant	**1,00**	1	5	Totally unimportant	**1,00**	1	4	Totally unimportant
EX10	**5,00**	5	5	Extremely important	**5,00**	5	5	Extremely important	**5,00**	4	5	Extremely important

Table 13. Evaluation of indicators concerning the QRM approach: exploitation of strategic variability.

Code	Indicators	Median	Rating
EX27	We recognize strategic variability and try to exploit it	**5,00**	Extremely important
EX28	We eliminate bad variability out of our process	**5,00**	Extremely important

Table 14. Comparison between regions regarding the QRM approach: exploitation of strategic variability.

Code	BRA				EURO				USA			
	Median	Min	Max	Rating	**Median**	Min	Max	Rating	**Median**	Min	Max	Rating
EX27	**5,00**	4	5	Extremely important	**4,00**	3	5	Important	**4,50**	2	5	Important
EX28	**5,00**	3	5	Extremely important	**3,00**	2	3	Neutral	**5,00**	5	5	Extremely important

Table 15. Evaluation of indicators concerning the QRM approach: creating spare capacity for critical resources to cope with variability effects.

Code	Indicators	Median	Rating
EX23	We work with a short and accurate planning horizon	**5,00**	Extremely important
EX22	We do not aim for maximum utilization, so that we gain flexibility/robustness	**5,00**	Extremely important
EX24	You can buffer variability on three ways: time, capacity and inventory. Our buffers exist mainly of idle capacity, which enables us to have little till no inventory and quicker response	**4,00**	Important
EX01	Full plant capacity utilization is not a manufacturing management priority.	**3,00**	Neutral
EX04	Productivity is not the main performance evaluation criterion	**2,00**	Unimportant

Table 16. Comparison between regions regarding the QRM approach: creating spare capacity for critical resources to cope with variability effects.

Code	BRA				EURO				USA			
	Median	Min	Max	Rating	**Median**	Min	Max	Rating	**Median**	Min	Max	Rating
EX23	**5,00**	4	5	Extremely important	**5,00**	2	5	Extremely important	**5,00**	5	5	Extremely important
EX22	**4,00**	2	5	Important	**5,00**	1	5	Extremely important	**5,00**	5	5	Extremely important
EX24	**3,00**	1	5	Neutral	**4,50**	3	5	Important	**5,00**	4	5	Extremely important
EX01	**1,00**	1	3	Totally unimportant	**3,50**	1	5	Neutral	**4,00**	2	5	Important
EX04	**1,25**	1	2	Totally unimportant	**2,50**	1	3	Unimportant	**3,00**	1	5	Neutral

Table 17. Evaluation of indicators concerning the QRM approach: using the POLCA system to transfers parts between cells.

Code	Indicators	Median	Rating
EX25	Production at a workstation starts only when both authorization, material and capacity at the required workstations are available	**5,00**	Extremely important

Table 18. Comparison between regions regarding the QRM approach: using the POLCA system to transfers parts between cells.

Code	BRA				EURO				USA			
	Median	Min	Max	Rating	**Median**	Min	Max	Rating	**Median**	Min	Max	Rating
EX25	**4,00**	4	5	Important	**5,00**	2	5	Extremely important	**5,00**	4	5	Extremely important

Table 19. Evaluation of indicators concerning the QRM approach: using time-based supply management.

Code	Indicators	Median	Rating
EX20	We consider delivery time as crucial criterion in selecting suppliers	**4,75**	Important
EX18	Our suppliers are aware of the power of time	**4,75**	Important
EX21	In some cases, we are willing to pay more for a supplier with a shorter delivery time	**4,25**	Important
EX19	We are able to work without stocks, due to the short delivery time(s) of our supplier(s)	**4,00**	Important
EX16	We train suppliers to improve lead time reduction	**4,25**	Important
EX14	Our key suppliers are located in close proximity to our plants	**4,00**	Important
EX17	We seek to work with smaller suppliers in order to influence them towards the reduction of lead time	**3,00**	Neutral
EX15	We do not adopt the practice of gain quantum discount to avoid to receive infrequent shipping of large quantities	**2,75**	Unimportant

Table 20. Comparison between regions regarding the QRM approach: using time-based supply management.

Code	BRA				EURO				USA			
	Median	Min	Max	Rating	**Median**	Min	Max	Rating	**Median**	Min	Max	Rating
EX20	**4,00**	3	5	Important	**4,50**	2	5	Important	**5,00**	4	5	Extremally important
EX18	**4,25**	4	5	Important	**3,50**	2	5	Neutral	**5,00**	4	5	Extremally important
EX21	**4,00**	3	5	Important	**4,50**	2	5	Important	**5,00**	3	5	Extremally important
EX19	**4,00**	3	5	Important	**3,50**	1	5	Neutral	**5,00**	5	5	Extremally important
EX16	**4,50**	4	5	Important	**1,50**	1	5	Totally unimportant	**5,00**	4	5	Extremally important
EX14	**4,50**	3	5	Important	**2,00**	1	5	Unimportant	**5,00**	1	5	Extremally important
EX17	**3,50**	3	4	Neutral	**2,50**	1	5	Unimportant	**3,00**	1	5	Neutral
EX15	**3,00**	3	5	Neutral	**1,50**	1	4	Totally unimportant	**1,00**	1	3	Totally unimportant

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